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# Forecasting Carbon Emissions in States of Hawaii, California, Colorado, and Florida; The Effects of States' Renewable Portfolio Standards

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**Abstract**

In this paper, we present four ARIMA (Autoregressive Integrated Moving Average) models for forecasting the future trends in carbon emissions of four states in the United States: the three states of Hawaii, California, and Colorado whose RPS (Renewable Portfolio Standard) laws set the most ambitious renewable targets, and the State of Florida, which presently has now RPS. The State of Florida is used as a baseline for comparing the effects of RPS laws on emissions. For each of the three states of Hawaii, California, and Colorado we run simulations under two scenarios. In scenario 1, we forecast the carbon emissions through 2050 of these states based on available emission data from 1980 through 2014, which include data for the years following the enactment of their RPS laws. In scenarios 2, we assume that no RPS laws were ever enacted in these states and use the emission data from 1980 to the year the RPS laws were enacted and forecast their carbon emissions through 2050. The results of the two scenarios are discussed in relation to the effectiveness of the RPS laws on emission reduction for these states.

Keywords: *Carbon Emissions, Autoregressive Integrated Moving Average Model, Renewable Portfolio Standards*

## 1. Introduction

In 2007, the U.S. total carbon emissions reached its peak of 5983 Million Metric Tons (MMT) which was 19% above its 1990-level, as shown in Fig. 1. Since then it has had a declining trend. Although the decline has not been monotonic, it did reach a trough of 5171 MMT in 2016 (U.S. EIA, 2017) (Statistica, 2016) which was only 2.84% above the 1990-level. This is a significant decline by any measure. Various researchers have cited different reasons for this decline, including:

- decline in the U.S. economy output in the years following the financial crisis of 2008-2009 (Peters, et. al. 2012) (Guardian, 2010),
- increase in use of natural gas (Feng, et. al., 2015),
- federal regulations imposed by Obama Administration (Adler, 2011) ( McCarthy and Copeland, 2016),
- and state-mandated regulations, and in particular, the Renewable Portfolio Standards (LBL, 2016).


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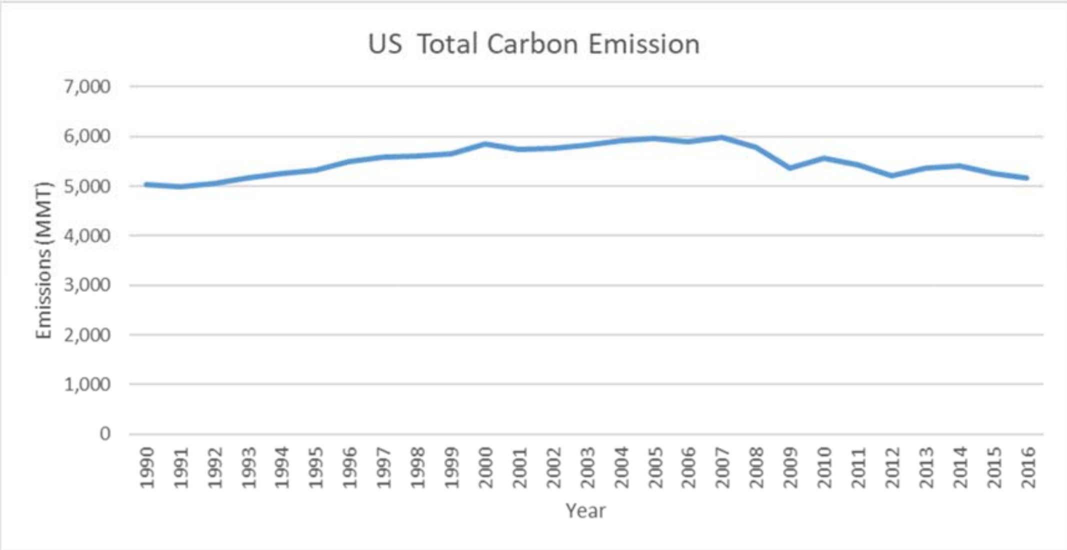


**Fig. 1: The U.S. total carbon emissions from 1990 to 2016 (U.S. EIA, 2017)**

In the absence of any federal mandate on reducing the U.S. carbon emissions, and in light of recent federal energy deregulations by present administration, and in particular, deregulation of coal industry, the role of states in mandating emission reduction is now more essential. A large number of states in the U.S. have enacted legislations mandating Renewable Portfolio Standard (RPS) requiring utility companies to produce a certain percentage of their electricity from renewable resources (U.S. EIA, 2012). While the state of Hawaii has the most ambitious target of 100% renewable electricity by 2045 (Hawaii State Energy Office, 2018), the state of California has set a goal of 50% renewable power production by the year 2030 (California Public Utility Commission, 2018). The state of Colorado requires production of 30% renewable electricity by 2020 (Colorado Energy Office, 2018). Overall, 29 states and the District of Colombia have adopted mandatory RPS along with 7 states that have voluntary goals (See Fig. 2) (LBL, 2016). The remaining states have no clear renewable energy policy including, ironically, the State of Florida, which has one of the most abundant supply of renewable resources, especially in solar energy (Khoie and Yee, 2015).

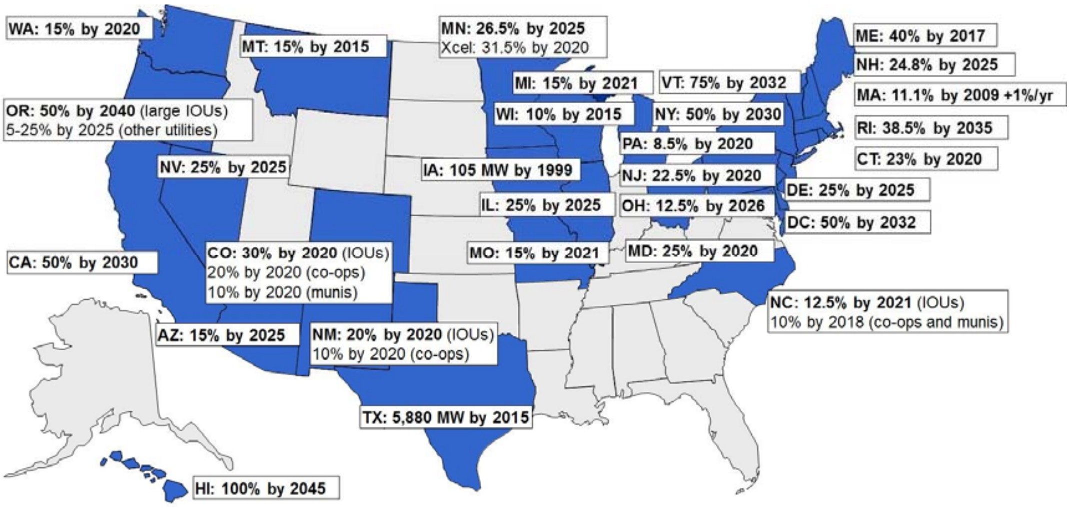


**Fig. 2: Renewable Portfolio Standards of the United States (LBL, 2016).**

In this paper, we present four ARIMA models for forecasting the future trends in carbon emissions of four states in the United States: the three states of Hawaii, California, and Colorado whose RPS laws set the most ambitious renewable targets, and the State of Florida, which presently has now RPS. The State of Florida is used as a baseline for comparing the effects of RPS laws on emissions. For each of the three states of Hawaii, California, and Colorado we run simulations under two scenarios.

- In scenario 1, we forecast the carbon emissions through 2050 of these states based on available emission data from 1980 through 2014, which include data for the years following the enactment of their RPS laws.
- In scenarios 2, we assume that no RPS laws were ever enacted in these states and use the emission data from 1980 to the year the RPS laws were enacted and forecast their carbon emissions through 2050.

## 2. Autoregressive Integrated Moving Average (ARIMA) Model

The general form of the ARIMA model is given by (Chen, et. al, 2010):

$$y_t = \mu + \varphi_1 y_{t-1} + \varphi_2 y_{t-2} + \cdots + \varphi_p y_{t-p} - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} - \cdots - \theta_q \varepsilon_{t-q} \qquad eq. (1)$$

Where:
$y_t$ is the predicted value for year $t$,
$y_{t-1}$ is the predicted value for year $t-1$,
$\mu$ is a constant term for a non-zero average trend,
$\varphi_p$ terms are autoregressive term (AR),
$p$ is the order of autoregressive process,
$\theta_q$ terms are moving average parameters (MA),
$q$ is number of lagged forecast errors in prediction model,
$\varepsilon_q$ terms are forecast errors.

In order to stationarize the predicted trends and mask seasonal variations, the order of differencing parameter, d is determined for each state:

- California – ARIMA( p= 7, d= 1, q= 0 )

  Average Max Error of ±13.5% @ 80% confidence
- Colorado – ARIMA( p= 12, d= 1, q= 0 )

  Average Max Error of ±24.4% @ 80% confidence
- Hawaii – ARIMA( p= 13, d= 2, q= 1 )

  Average Max Error of ±18.3% @ 80% confidence
- Florida – ARIMA( p= 17, d= 1, q= 0 )

  Average Max Error of ±28.7% @ 80% confidence

When the order of differencing, $d = 1$ $then$ $y_t = Y_t - Y_{t-1}$ and when

$$d = 2 \quad then \quad y_t = (Y_t - Y_{t-1}) - (Y_{t-1} - Y_{t-2}).$$

In the above equations, $y_t$ is the predicted value for the year $t$ and $Y_t$ is the value of original data at year $t$. The parameters $p,$ and $q$ are determined based on a Box-Jenkins (Chen, et. al., 2010) method using series of simulations resulting in least prediction error of known years. The adaptive nature of the model ensures that historical trends associated to policy changes are reflected in future trends.

The ARIMA model for each state is simulated using R- package and is validated with 2010-2014 emission data for each state from data reported by the U.S. Energy Information Administration (U.S. EIA 2017). The order of the fit is adjusted as appropriate to achieve a minimum absolute error between the predicted data and the know emission data in the years 2010 through 2014.

## 3. Results

The total annual carbon dioxide emissions from fossil fuel consumption for each of the four states is shown in Fig. 3. The years of enactment of RPS laws in states of California, Colorado, and Hawaii are marked in order to serve as an indicator in further analysis in comparing trends in carbon emissions before and since RPS laws were enacted. The states' emission data used in our simulations are for the years 1980 – 2014.

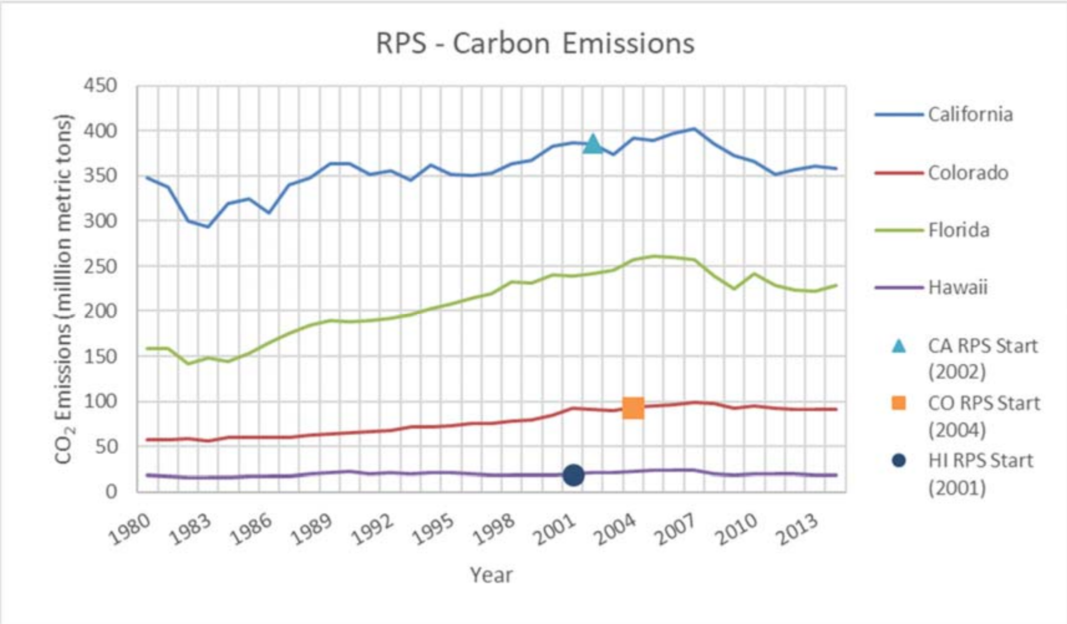


**Fig. 3: The states' total carbon emissions from 1980 to 2015. The year of RPS enactment for each state is also marked. (U.S. EIA, 2016).**

The State of California, as the largest economy in the United State has had the highest emissions of all states. In 1980, the state of California produced 348 MMT, which increased to 363 MMT in 1990 and reached its peak at 402 MMT in 2007. Since then it has declined to 358 MMT in 2014. Similar data for the other three states studied in this work are shown in Tab. 1.

**Tab. 1: Highlights of emissions (in MMT) data for the four states studied in this work.**

| State | 1980 Emissions | 1990 Emissions | Peak Emission | Year of Peak Emissions | 2014 Emissions |
|---|---|---|---|---|---|
| California | 348 | 363 | 402 | 2007 | 358 |
| Colorado | 58 | 65 | 99 | 2007 | 92 |
| Hawaii | 18 | 21 | 24 | 2007 | 18 |
| Florida | 158 | 188 | 260 | 2005 | 228 |

Noteworthy in the above emission data are the following:

- The state of Florida has had the highest rate of increase in emissions in the 25 years between 1980 and 2005.
- The state of Colorado was on a sharp rise in emissions in the years prior to and leading to enactment of its RPS laws in 2004.
- The state of Hawaii's emissions while increasing from 18 MMT in 1980 to 24 MMT in 2007 (a relatively substantial rise), has had a relatively flat emission curve in the past 35 years.
- Most states reached their peak in 2007, except Florida, which reached its peak earlier in 2005.

The forecast results for the state of California are shown in Fig. 4. The green curve shows the emission forecast for the state with the enactment of RPS laws in California, which took place in 2002. The red curve shows the emission forecast if the state had not enacted any RPS laws. The forecast results for all four states are shown in Fig. 5.

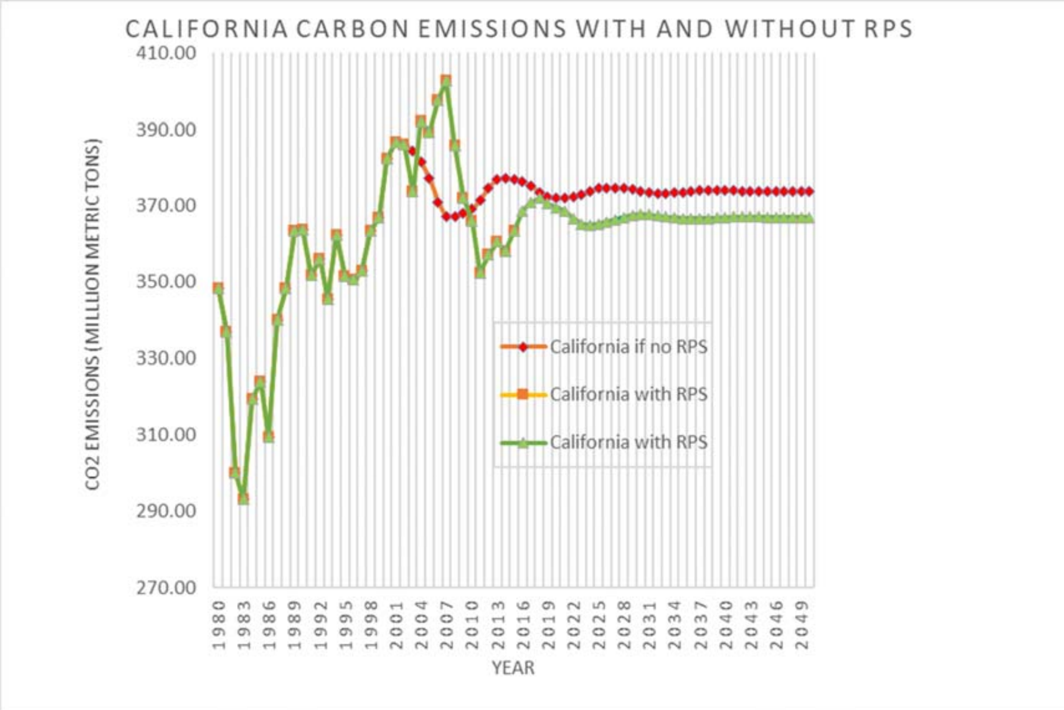


**Fig. 4: ARIMA forecast results for the State of California with and without enactment of RPS.**

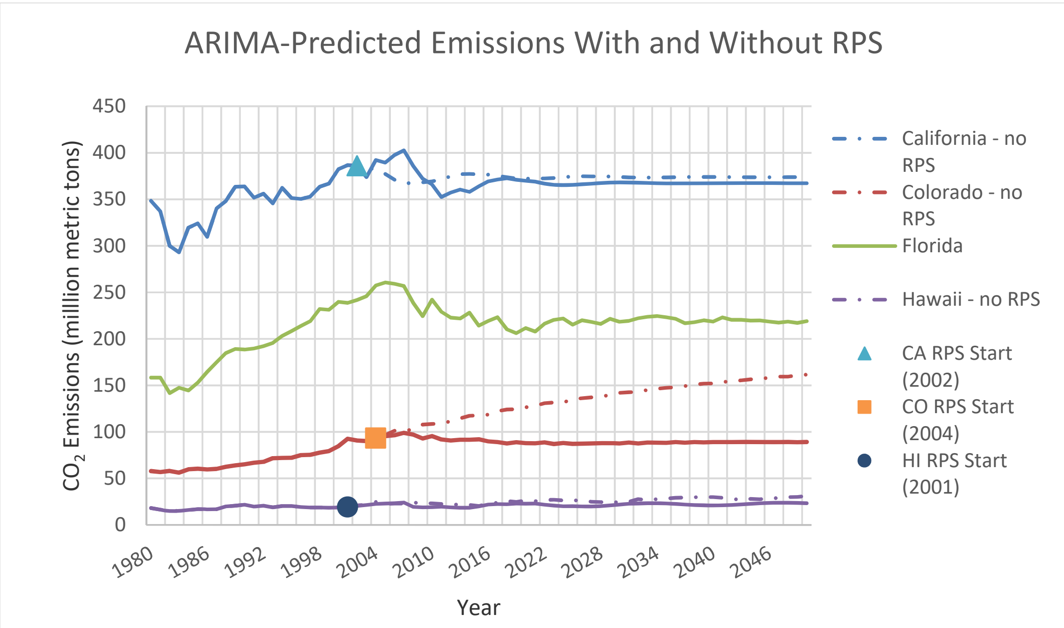


**Fig. 5: ARIMA forecast results for all four states with and without enactment of RPS.**

Our forecast results show that with the enactment of RPS laws in California, the state's 2050 emissions would reach 101% of its 1990-level, whereas without the enactment of its RPS laws, the state total emissions would have reached 103% of its 1990-level. The results shown in Figs. 4 and 5 for all four states are summarized in Tab. 2.

**Tab. 2: The emissions of states as percentage of 1990-levels with and without RPS enactment**

| State | 1990 Base Emissions | 2014 Emissions | 2014 Emissions as % of 1990-Base | 2050 Emissions | 2050 Emissions as % of 1990-Base |
|---|---|---|---|---|---|
| California | 363 | 358 | 98% | 367 | 101% |
| California if no RPS | | 377 | 104% | 374 | 103% |
| Colorado | 65 | 92 | 140% | 89 | 137% |
| Colorado if no RPS | | 117 | 180% | 162 | 248% |
| Hawaii | 21 | 18 | 85% | 23 | 107% |
| Hawaii If no RPS | | 22 | 100% | 31 | 144% |
| Florida | 188 | 228 | 121% | 219 | 116% |

As shown in Tab. 2, in all three states of California, Colorado, and Hawaii, the RPS laws have been effective in lowering their emissions both in 2014 and 2050 levels. In the state of Colorado, the RPS laws have been particularly effective. The state of Colorado's total emissions would have reach to 248% of its 1990-level, if the state had not adopted its RPS in 2004. With enactment of its RPS, the state of Colorado would produce 89 MMT of carbon emission which is 137% of its 1990-level. This is a significant reduction in emission by the state of Colorado, which was on a steep rise in emissions in the years prior to its enactment of RPS laws.

The state of Hawaii also would have seen a relatively significant rise in its emissions (144% of its 1990-level in 2050) had it not been for their ambitious renewable target of 100% by 2045. Our forecast model for the state of Hawaii predicts that the total emissions of Hawaii will be 107% of its 1990-levels in 2050. The state of Florida, without any RPS laws is expected to reach 219 MMT of total carbon emissions in 2050, which is 116% of its 1990-level. This increase in emissions by the state of Florida is in contrast to the three states of California, Colorado, and Hawaii in which the RPS laws were shown to be effective in keeping their emission levels from significantly rising in 2050.

## 4. Conclusions

The results of our ARIMA models (summarized in Tab. 2) show that in the three states with RPS, the total emissions in 2050 will likely be less than what they would been if the states had not adopted their RPS laws. For the state of Californai, the RPS laws would make a 2% difference (103% of its 1990-level without RPS versus 101% of its 1990-level with RPS) in total emissions in 2050. The state of Colorado the RPS laws would make a significant differrence of 111% in total emissions (248% of its 1990-level without RPS compared to 137% of its 1990-level) in 2050. Similarily, the RPS laws in the state of Hawaii would account for a 37% difference in their projected emissions (144% of its 1990-level without RPS as opposed to 107% with RPS) in 2050. The state of Florida without any RPS laws will have total emissions that are 16% higher than its 1990 baseline.

It is noteworthy that the RPS laws affect the emissions by the electricity sector and ARIMA modelling of emission by the electricity sector alone will result in different future trends, which may hide the effects that production, transportation, installation, and operation of renewable electricity generation, have on other sources of emissions including residential, industrial, commercial and transportation sectors.

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